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Dilepton and Dihadron Production in Proton-Nucleus Collisions at 800 GeV *

The E-772 and 789 Collaborations

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Abstract

A high statistics measurement of the atomic mass dependence of Drell-Yan, J/ψ, ψ' and Υ production induced by 800 GeV protons on deuterium, carbon, calcium, iron and tungsten targets has been performed at FermiLab (E772). The data consist of about 700,000 muon pairs covering the mass region 3 GeV $\leq M_{\mu\mu} <$ 14 GeV. No nuclear modification is seen in the production of massive muon pairs in the Drell-Yan region for 0.1 $< x_2 <$ 0.3. The relative dimuon yield for fractional antiquark momentum $x_2 < 0.1$ is slightly less than unity for heavy nuclei. J/ψ and ψ' production are strongly suppressed in heavy nuclei. An upgraded version of the spectrometer designed to measure two-body decays of neutral c and b-quark hadrons (E789) will be discussed.

The EMC effect, discovered in 1983 by the European Muon Collaboration in a deep-inelastic muon scattering experiments[1] from atomic nuclei, revealed a difference between the structure functions of heavy nuclei and that of deuterium. The EMC effect is also seen in electron and neutrino scattering. There has been general agreement on the depletion of the valence quark structure function in the region of quark momentum fraction 0.3 $\leq x_2 \leq 0.6$, however major disagreements exist in the region $x_2 \leq 0.1$. Experiment E772 at Fermilab has done a precise measurement of the ratios of the Drell-Yan (DY) cross section on a number of atomic nuclei in a kinematic regime that is sensitive to the sea antiquark distribution of the target. The New Muon Collaboration[2] has also performed detailed high statistics studies in the region of $x < 0.1$.

The proton-induced DY process in the region of $x_F \geq 0.2$ is dominated by the annihilation of a quark and an antiquark from the beam proton and target nucleon, respectively. Hence the ratio of cross sections per nucleon provides a direct measure of the modification of the antiquark structure functions in nuclei. We have reconstructed over 450k DY muon pairs from Deuterium, Carbon, Calcium, Iron and Tungsten targets at 800 GeV. These results show no A-dependence in the DY cross section ratio, but there is evidence of shadowing in the low x_2 region for heavy targets.

Recent results[3] from relativistic heavy-ion collisions indicates a suppression of J/ψ production in central versus peripheral collisions. This observation was predicted to be evidence for high energy density or quark gluon plasma formation. This prediction has generated considerable interest in the subject of hadron-induced J/ψ production[4]. We have studied the nuclear dependence of J/ψ, ψ' and $\Upsilon(1s)$ production.

In this paper we will discuss the results of the E772 measurements and in a separate section present the physics motivation and plan for the upcoming run to study two body decays of neutral c and b-quark hadrons (E789)[5].

Experimental Setup of E772 measurements

The E772 spectrometer is characterized by its ability to handle very high rates and provides excellent mass resolution. The spectrometer was used in a closed aperture configuration, permitting the use of a very high-intensity primary 800 GeV proton beam. The maximum flux used for these measurements was 2×10^{12} protons per beam spill (20 Sec) on a 10% interaction-length target. The wire chamber, hodoscope, trigger and readout system for E772 were similar to those used for $E605$[6]. Three spectrometer settings were chosen to cover a wide dimuon mass range (3 GeV $< M(\mu^+\mu^-) <$ 14 GeV). Targets of liquid deuterium, carbon, calcium, iron and tungsten were used in these measurements. The targets were interchanged at regular intervals to reduce the errors due to long term drifts and changes in the efficiency. Several monitors were employed to check the beam intensity and duty factor for each beam spill. Detailed Monte Carlo simulations of the spectrometer, including the trigger were performed to study any possible target dependence of the spectrometer's acceptance. The acceptance of the solid targets was found to be 0.9% larger than for the liquid deuterium target. No significant differences in the acceptance were found as a function of dimuon mass or x_2. The systematic uncertainty of these measurements is $\leq 2\%$.

Drell-Yan Results

Fig. 1 shows the composite dimuon mass spectrum, uncorrected for the spectrometer acceptance, for the ^2H target. The acceptance corrected spectra from the three spectrometer settings are shown for the ^2H target in Fig. 2. A simple calculation of the DY cross section in the leading log approximation ($q(x) \rightarrow q(x, M^2)$), using the Eichten, et al[7]. structure functions, is also shown in Fig. 2. This calculation is normalized to the data, giving a K factor of 2.2 ± 0.2. The Drell- Yan data presented here are in the mass region away from quarkonium states, specifically 4 GeV $\leq M \leq$9 GeV and M $\geq$ 11 GeV. The DY yield ratio per nucleon R $= Y_A/Y_{2H}$ for each heavy target as a function of x_2, for muon pairs with positive x_F, is shown in Fig. 3. The mean x_F in the data set is 0.26. No nuclear effect is seen in the antiquark sea in the range of $0.1 < x_2 < 0.3$. A slight but experimentally significant depression of the antiquark ratio is seen in the heavest targets for $x_2 < 0.1$. Similar behaviour has been seen in lepton scattering data, but with more pronounced shadowing at low x_2. The nuclear dependence of the P_T distribution is shown in Fig. 4. The data show a similar dependence compared to that observed in the P_T distribution of the pion induced DY data of the NA10 Collaboration at 286 GeV[8].

Resonance Data

The spectrometer mass resolution of about 150 MeV, at a mass of 3 GeV, provided excellent separation between the J/ψ and ψ' peaks, as shown in Fig. 1. The J/ψ, ψ' and $\Upsilon(1s)$ yields were obtained by a fit to the DY continuum and the resonance peaks. The A-dependence for the J/ψ, ψ' and $\Upsilon(1s)$ yields integrated over x_F and P_T is shown in Fig. 5 along with the DY data. In contrast to the DY data, which give R very close to unity, the J/ψ, ψ' and $\Upsilon(1s)$ all show a significant depletion in heavy targets. Within the experimental accuracy, both the J/ψ and ψ' have a similar A-dependences well described by $A^{0.92}$. A larger exponent given by $A^{0.96}$ is measured for $\Upsilon(1s)$. The nuclear dependence of J/ψ production as a function of the target mass for various x_F bins is shown in Fig. 6. The dashed lines, which are A^{α} fits to the data, describe the observed A-dependence well, with α decreasing as x_F increases. The observed x_F dependence is in qualitative argeement with the NA3 data[9] at 200 GeV/c for hydrogen and platinum targets. Fig. 7 shows the nuclear dependence of the x_F distribution for the various targets. It is seen that the x_F dependence becomes larger for the heaviest nuclei. The nuclear dependence of J/ψ as function of P_T is shown in Fig. 8. The dashed lines are linear fits to the data. The slope of these fits is positive and increases with target mass. Positive slopes for the P_T dependence of R were also observed in other hadron-induced J/ψ measurements[9,10] as well as in relativistic heavy-ion collisions[11]. This similarity suggests a common origin.

A similar detailed study of the ψ' and $\Upsilon(1s)$ resonances is in progress. During the upcoming E789 run we will extend the measurements of the A- dependence of the J/ψ and ψ' resonances to the negative x_F region.

B and D Meson Production and Decay

The experiment (E789) is motivated by two recent discoveries. First is the observation of large mixing in the $B^o\bar{B}^o$ system[12]. This result suggests the possibility that CP-violation could be observed in a high statistics study of B^o meson decays. Second is the observation that the amplitude for $b \to u$ conversion might be large[13]. Recently the ARGUS and CLEO collaborations have published events showing evidence for charmless decays of B mesons. Model dependent theoretical analysis of these decays indicates V_{ub}/V_{cb} to be approximately 0.1. The sizable non-charm decay of B-mesons suggests that the branching ratios of $B \to h^+h^-$ decays could be of the order of 10^{-4} to 10^{-5}. The dihadron decay mode is simpler to calculate compared to other observed charmless B decay modes, hence these h^+h^- decays would contribute to a better determination of V_{ub}. Such dihadron decays have not been observed experimentally. Furthermore, the asymmetry in $B^o, \bar{B}^o \to K\pi$ decays is sensitive to CP-violation[14]. Measurements of the branching ratio of $B^o \to h^+h^-$ decays and the B production cross section would be an improtant step for choosing the most suitable channels for measuring CP- violation in the B system.

Even though the first evidence[15] for b-quarks was observed in hadron collisions, most of the existing data on B meson production and decay were obtained from e^+e^- collider experiments. The luminosity at existing colliders severely limits the B production rate.

During several years of running at e^+e^- colliders only a few hundred exclusive B decay events have been reconstucted. The average multiplicity of these decay channels is about five, contributing to the difficulties of reconstruction. The detection of B decays in fixed target experiments has been suggested by Bjorken[16], where the production rate of b- quark hadrons is orders of magnitude greater than that at current e^+e^- colliders. Currently in the Fermilab fixed target program there are three experiments (E789, E771 and E791) which plan to detect B-meson decays. In the following sections we will discuss the experiment E789, which focuses on the detection of $B \rightarrow h^+h^-$ and $D \rightarrow h^+h^-$ decays.

Proposed Measurements

The main goal of the E789 is to search for tha $b \rightarrow u$ transition in the dihadron decay mode of the B-Meson. We will determine the values (or upper limits) of the branching ratios of the following decays: $B_d, B_s \rightarrow \pi^+\pi^-$, K^+K^-, $p\bar{p}$, $\pi^\pm\pi^\mp$; $\Lambda_b \rightarrow p\pi^-$, pK^-; $\bar{\Lambda}_b \rightarrow \bar{p}\pi^+$, $\bar{p}K^+$. These decay modes have never been observed. The lifetime and masses of B_d, B_s and Λ_b will be measured in this experiment. Neither the B_s nor the Λ_b have yet been detected. The expected mass resolution is 5 MeV at mass of $\simeq$ 5.3 GeV.

The dynamics of b-quark production in hadron-hadron collisions is poorly known. This experiment can measure the product of the production cross section and the branching ratio of several inclusive decays of the B meson (e.g. B $\rightarrow J/\psi X$, $\psi' X$). The branching ratios of these decays are already known. The observation of these decays in E789 would provide the first measurement of the dynamics of B production in hadron-hadron collisions. The silicon strip detectors will allow the selection of J/ψ and ψ' events which originate from a downstream vertex. Such events most probably result from B-meson decays. The J/ψ and ψ' will be identified through their dimuon decays.

E789 will provide a higher sensitivity search for $B \rightarrow \mu^+\mu^-, e^+e^-$ and μe decays. The current upper limits of these branching ratios are 10^{-5}. The DY continuum originating in the target will be greatly suppressed by the vertex detectors allowing us to reach a sensitivity of about 10^{-6} for these decays. Furthermore, unlike the ARGUS and CLEO experiments, we are also sensitive to $B_s \rightarrow l^\pm l^\mp$ decays.

Direct evidence of $B - \bar{B}$ mixing has been reported by both the ARGUS and CLEO collaborations in fully reconstructed B decays. $B - \bar{B}$ mixing has also been observed by measuring the excess of like sign dileptons in semileptonic decays of B's. The primary semileptonic decays of b $\rightarrow l^-\bar{\nu}_l c$ and $\bar{b} \rightarrow l^+\nu_l c$ normally yield a pair of leptons with opposite charges. Through mixing, a B^o meson can transform into its antiparticle and decay as $\bar{B}^o$, signalled by the appearance of a like-sign lepton pair. We will have less contamination from non-B decay backgrounds because of the rejection provided by the silicon vertex detectors. Our measurements will be sensitive to $B_s - \bar{B}_s$ mixing in addition to $B_d - \bar{B}_d$ mixing.

Before embarking on the B decay study, we will be tuning up our detectors using the higher production cross section ($\sim 20\mu b$) and branching ratio decays of D mesons. During this short run we will study $D^o, \bar{D}^o \rightarrow K^{\pm}\pi^{\mp}, K^+K^-, \pi^+\pi^-$. This measurement will improve the current sensitivity to these decay modes. We expect to reconstruct about 10^5 events in $D \rightarrow \pi K$ and 10^4 events in $D \rightarrow KK$ and $\pi\pi$ decay modes. Furthermore we will be improving the current upper limits for the rare decay modes $D \rightarrow l^+l^-$. During a one month run we expect to reach a sensitivity of better than 10^{-6} for the dilepton decay modes of D mesons. During this run production and decay of other hadrons, such as η_b, χ_o, η_c, χ_c, etc. will also be search for and studied.

The E789 spectrometer is the same one used by the E605/E772 experiments with the addition of a silicon vertex spectrometer just down stream of the target and by replacing the station 1 MWPC's with drift chambers. The E605/E772 spectrometer has been used successfully in detecting di-hadrons and di-leptons resulting from proton-nucleus collisions. The silicon vertex spectrometer, which is a crucial component of the E789 detector system, will be placed very closed to the beam axis. Since these detectors will be subjected to a very high rate environment, they will suffer significant radiation damage. We have studied the performance of a similar microstrip detector using a proton beam at Los Alamos Meson Physics Facility. The detector performs well up to fluence of 1×10^{14} particles/cm^2. The results of this study will be published elsewhere[17]. We expect the silicon detector to perform well for at least one fixed target run at Fermilab ($\sim$ 6 months).

Two major types of backgrounds are expected. The first arises from the production of particles at least one of which is relatively long-lived and decays downstream of the target. The second type of background is due to prompt hadron pairs produced in the target. Beside these two backgrounds there is a large soft pion background, in the silicon spectrometer during each RF bucket. A detailed Monte-Carlo simulation has been carried out to study these backgrounds and the rejection efficiency one can achieve without excessively losing a lot of the B efficiency. Rejection of these backgrounds is achieved through cuts on impact parameter, Z-vertex, distance of closest approach, invariant mass and spectrometer acceptance. The reconstruction efficiency of these simulations is about

35% and the contributions from the first type of backgrounds to the signal is insignificant, whereas for the second type, direct target dihadrons, we can achieve a rejection of $\sim 10^5$.

Summary

Fermilab experiment E772 shows no nuclear effect on the antiquark sea in the range of $0.1 < x_2 < 0.3$. A small depletion of the antiquark sea is seen in the heaviest target for $x_2 < 0.1$. We have also presented a detailed study of the nuclear dependence of J/ψ, ψ' and $\Upsilon(1s)$ resonance production in proton-nucleus collision. Both the J/ψ and ψ' are strongly suppressed in heavy nuclei, whereas the suppression of $\Upsilon(1s)$ is relatively smaller.

The study of B-meson decay is an extremely rich developing field, with the ultimate goal of studying CP nonconservation in neutral and charged bottom particles. We have presented an experiment which will study specific decay channels of c and b-quark hadrons. The experiment will begin this summer and we anticipate exciting results to appear in the near future.

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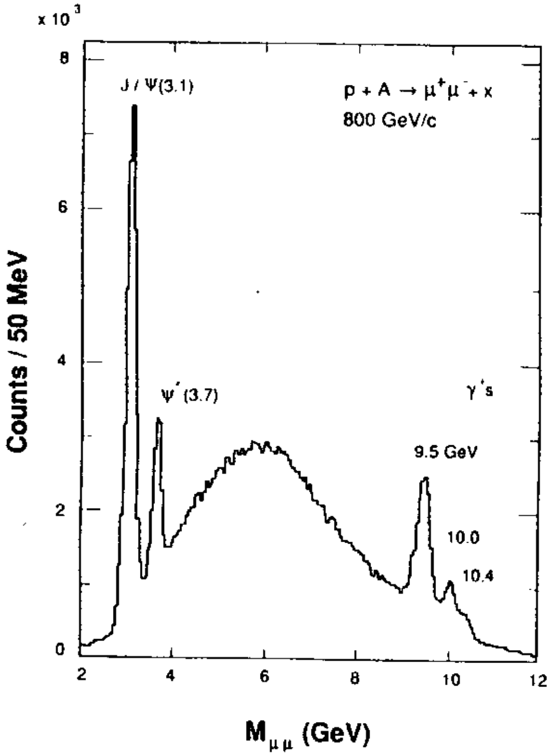

Fig. 1. Dimuon mass spectrum from E772.

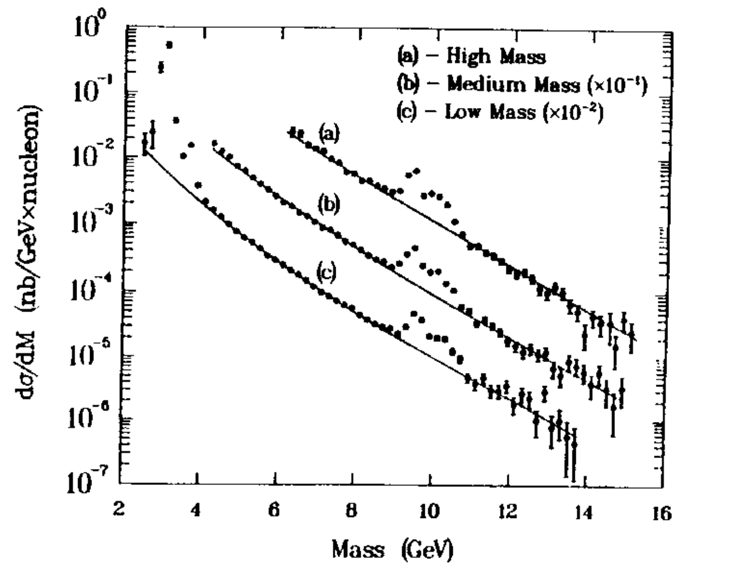

Fig. 2. Acceptance corrected mass spectra at the three spectrometer settings for the D_2 target. The solid curves are calculations of the Drell-Yan cross section, normalised to the data, using the structure functions of Eichten *et al.*[7]

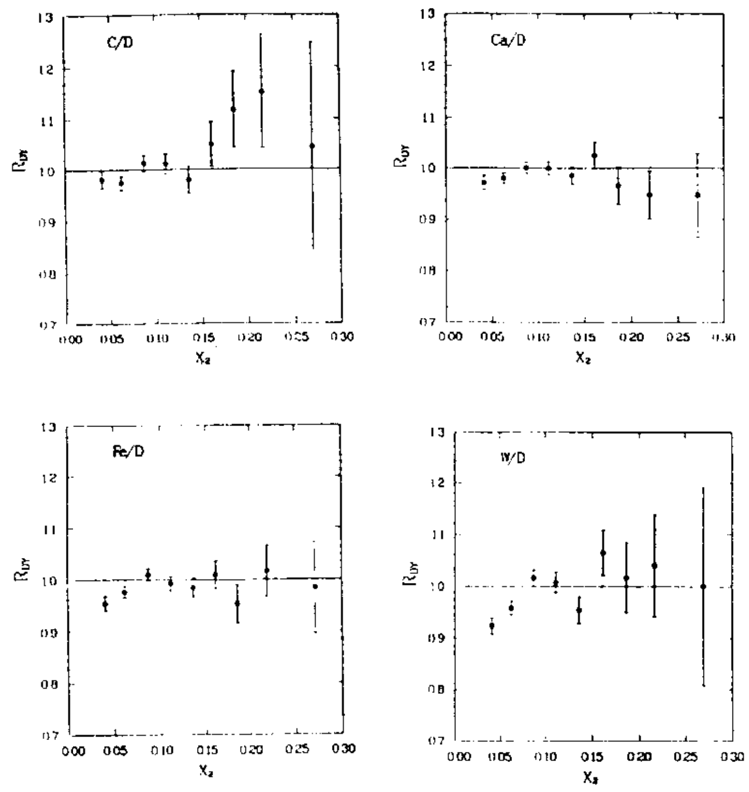

Fig. 3. Ratios of the Drell-Yan dimuon yield per nucleon, Y_A/Y_D for positive X_F. as a function of x_2.

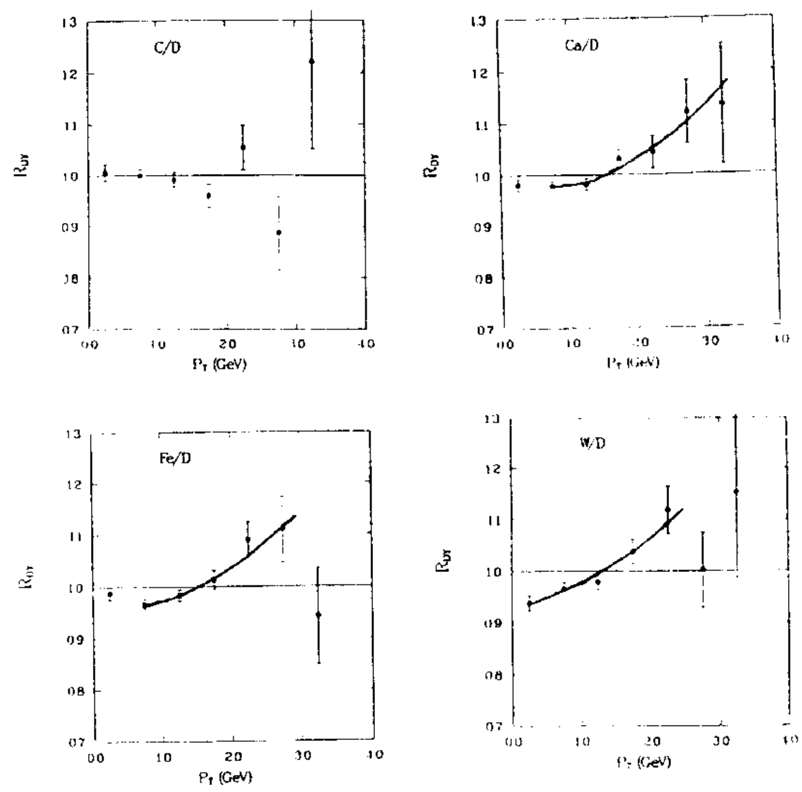

Fig. 4. Ratios of the Drell-Yan dimuon yield per nucleon, Y_A/Y_D as a function of p_t.

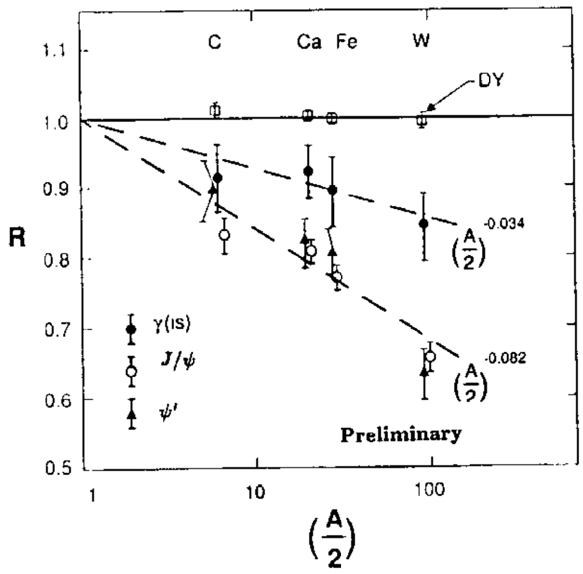

Fig. 5. Preliminary Nuclear dependence of J/ψ, ψ' and $\Upsilon(1s)$ production measured in E772 along with Drell-Yan data.

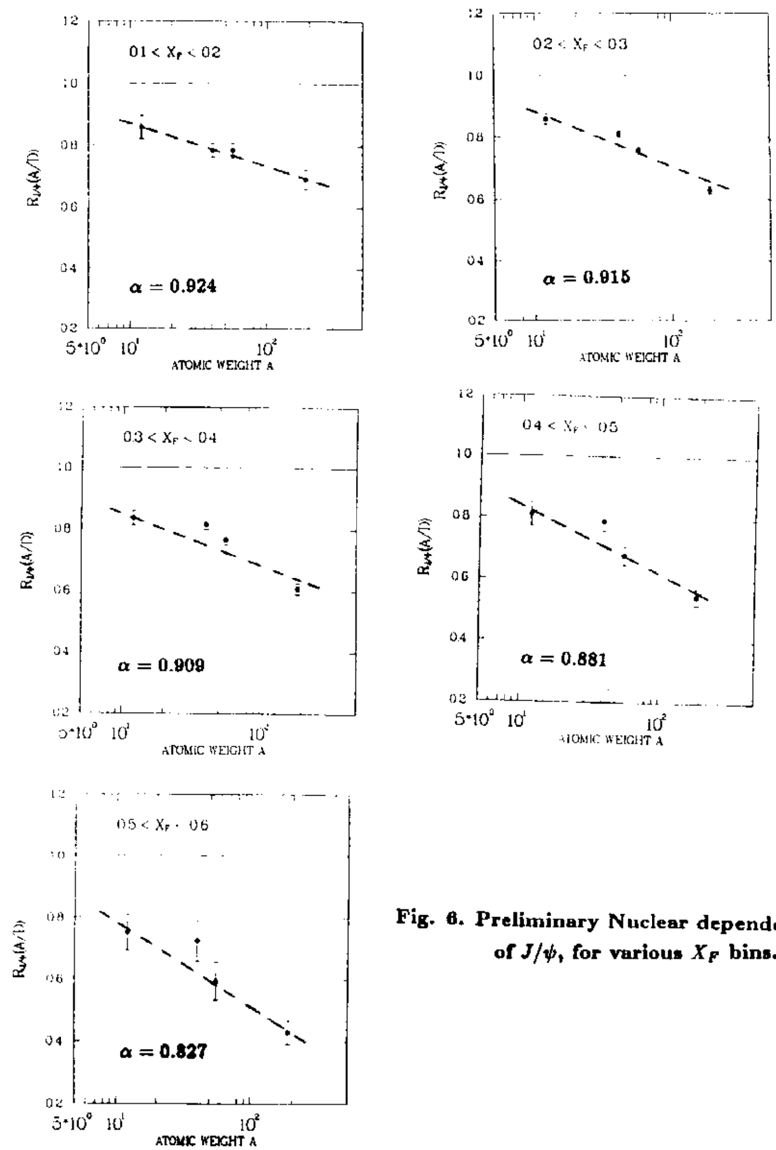

Fig. 6. Preliminary Nuclear dependence of J/ψ, for various X_F bins.

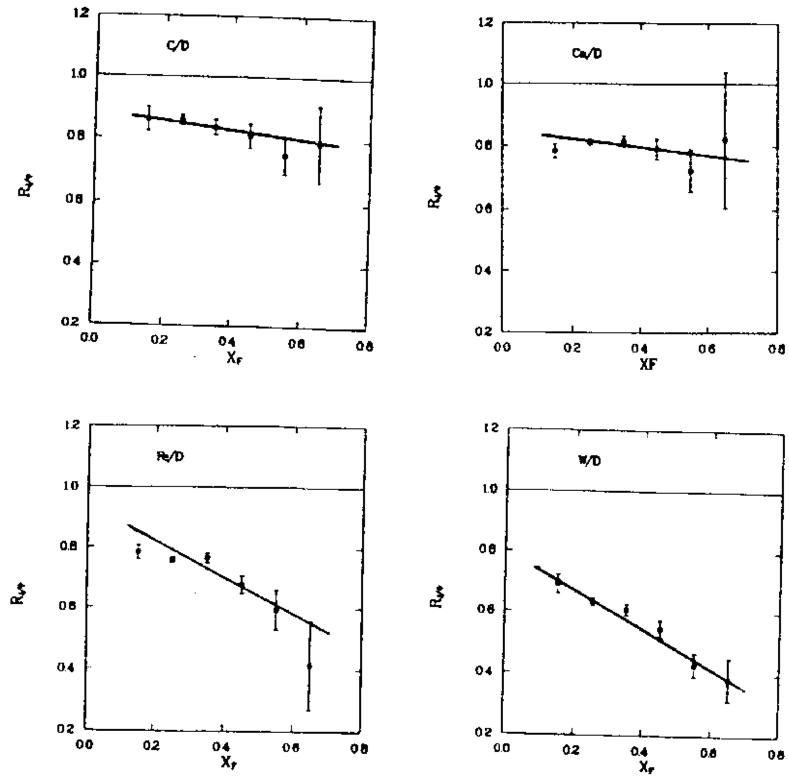

Fig. 7. Preliminary Ratios of the J/ψ yield per nucleon, as a function of X_F.

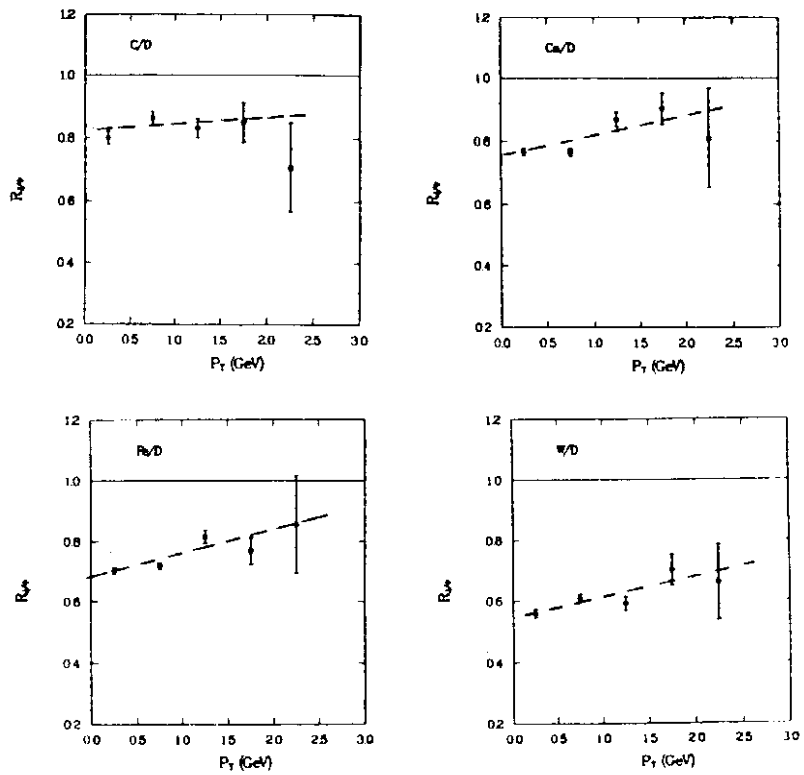

Fig. 8. Preliminary Ratios of the J/ψ yield per nucleon, as a function of p_t.